7 Ovens

Introduction

Many food service operations rely heavily on the versatility of ovens. Operators can cook varieties of foods in large quantities with a single appliance. As a result of their versatility, ovens are the most widely used appliance in the food service industry. An oven can be simply described as a fully enclosed, insulated chamber used to heat food. But, there are many variations of the basic concept in the commercial kitchen. The most common types of commercial ovens include standard, or conventional ovens, convection ovens, combination oven/steamers (also known as combination or combi ovens), conveyor (pizza) ovens, and rotisseries. Additionally, an emerging group of high-performance hybrid ovens have been carving out a niche in today’s fast-paced culinary world. These rapid cook ovens are creating new food service opportunities for pubs, kiosks, quick-service restaurants, delicatessens, hotels and movie theaters.

Operators know that fresh-baked signature desserts, crusty breads, and familiar comfort foods, such as roasted meats and potatoes, are fundamental menu items. In addition to the traditional uses of ovens for roasting and baking, they may be used to cook a surprising range of foods usually associated with other appliances. For example, ovens in high-volume kitchens prepare large quantities of griddle standards such as bacon, eggs, sausages and French toast.[1]

Customized high-air velocity convection ovens using an “oil-less frying” technique can be used in place of a deep-fat fryer to cook French fries, onion rings, chicken nuggets, fish and other popular fried foods. In some cases, the cooked food produced using this technology contains less oil than food cooked using deep fat fryers.

Combination ovens are regularly used to proof dough, steam vegetables, cook and hold a wide variety of foods, rethermalize pre-plated meals and even broil steaks. The combination of a steam generator and a convection oven make these some of the most versatile ovens available.

Restaurant operators are increasingly cooking in plain view of their customers. Exhibition baking and the popularity of several types of ovens have increased due to this style of operation. Rotisserie ovens offer food service operators a unique opportunity to simultaneously cook and merchandise a variety of popular foods such as chicken, ribs, lamb and duck. Pizza ovens, also commonly found in plain view of the customer in the more upscale operations, once again mix product visibility with production. Pizzerias and other restaurants that require high throughput and product consistency have enjoyed great success with conveyor ovens. For example, one large seafood restaurant chain employs conveyor ovens for their complete menu production.

A concept that is growing in popularity with large food service operations—such as hotels, school commissaries, groceries, correctional facilities and even quick-service chains—is use of a centralized kitchen. Huge quantities of food are produced in a large central cooking facility and then delivered to multiple satellite kitchens, which may serve the food hours or days later. The food is prepared and chilled at the main kitchen, and later reheated by the satellite location. Rack ovens, cook/chill systems and rethermalization ovens are becoming more prevalent in these operations due to the requirements of high production and food safety.[2]

Ovens represent the largest appliance category in terms of the types of units manufactured of any of the major cooking equipment categories.[3] This versatility and diversity mean that they can be found in almost any type of food service operation.[4] A recent US study showed that 95% of commercial (non-institutional) operations reported using at least one type of oven; 98% of noncommercial (institutional) operations reported the same. The percentage of operations, commercial and institutional, using general bake ovens was 52% and 56%, respectively. Fifty percent of the operations in the commercial sector reported using convection ovens as compared to 83% of noncommercial operations. Pizza ovens accounted for 19% and 12%, respectively. Microwave ovens were popular in both sectors with installations in 71% of the noncommercial foodservice sector and 70% of the commercial operations.[1]

Commercial ovens are available in various configurations using a variety of energy sources–electricity, natural gas or liquid propane, and in some cases,

Figure 7-1. Double-stacked convection oven.
Photo: Blodgett Corp.

wood. Natural gas is the predominant fuel source for most commercial ovens, representing 55 to 60% of the installed base, but electric ovens are common and represent most of the remaining 40 to 45%.[5] Because of the variety of potential installations, oven manufacturers strive to be space conscious and flexible in their designs. Ovens can be either freestanding or in a counter-top/stackable configuration, as illustrated in Figure 7-1. Even some of the largest conveyor ovens can be stacked, allowing for high output in a relatively small footprint and the same can be said for large rack ovens, which are tall but relatively narrow. Manufacturers are also making smaller ovens to fill niche markets and the needs of low volume food service operators. In order to facilitate consistent and energy efficient operation, manufacturers are beginning to introduce sophisticated control packages to their products, including temperature measurement and feedback loops, on board diagnostics, and external communications capabilities.

Cooking Processes

Ovens cook food products using all three fundamental heat transfer methods, convection, conduction, and radiation, both alone and in various combinations. The simplest model of an oven is a box that cooks the food by transferring heat from the oven walls. The placing of air fans into ovens introduced forced convection into this process, which speeds up the cooking process and increases output. In early stone and brick ovens, food was placed directly on a hot slab or against the oven wall and the food was cooked primarily through conduction. This process has been updated and is the basis for modern deck and wood fired ovens, many of which also include a convection component and in some cases even include strategically placed radiant heat sources. In most oven designs, a thermostat controls the oven cavity temperature. In some cases, the oven humidity is also varied and controlled through the introduction of moisture in the form of steam into the cavity. Microwave and other rapid-cook ovens bombard the food product with waves of energy that agitate the molecules within the food product, causing the internal temperature to rise.

Types of Ovens

Standard or Conventional Ovens

Standard or conventional ovens use natural convection and radiant heat to cook food products. In general, these ovens do not mechanically circulate the air within the cavity. The burner or elements heat the air within the oven cavity as well as the cavity walls, causing currents of hot air that transfer heat to the surface of the food. The arrangement of pans in the oven and the texture of the food can affect the circulation of air, changing the cooking speed and uniformity. Two familiar types of standard ovens are the range oven and the deck/pizza oven. The range oven is the most familiar, since it is the kind most often found in residential applications. These ovens can be used for nearly all types of food preparation including breads, pies, meats, fish, poultry and baked potatoes. Standard ovens are ideal for precision baking because the natural flow of air within the oven cavity reduces the oven's impact on delicate food products such as meringues, cream puffs, pastry shells and other products that require a dry atmosphere. Standard ovens are the least expensive to purchase, and their production capacity is typically not as high as forced convection ovens.

Range Ovens. The most common standard oven–the range oven, also known as the general-purpose oven, is heated with atmospheric gas burners located directly below the oven cavity. Flue gases are routed around and/or through the cavity. In electric ovens the elements are placed in the top and bottom of the oven cavity, where they add both radiant and convective heat; they also may be placed underneath the bottom deck.

Figure 7-2.
Six-burner range with range oven.

Range ovens are part of a cooking unit or system (see Figure 7-2). The range oven forms the housing or base for the range top (i.e., burners, griddle, etc.), addressed in Section 5. The range/oven combination usually consists of the range system and only one oven cavity. Energy input ratings are often given for the complete range system. Typically, the energy input rate of a range oven will be between 35 kBtu/h to 45 kBtu/h for gas and 7 kW to 9 kW for electric.

Range ovens are normally specified for smaller operations. Their exterior dimensions are typically 36 inches (900 mm) wide by 30 inches (750 mm) deep by 30 inches (750 mm) high. They typically come equipped with a pan and support racks.

Figure 7-3.
Deck oven.
Photo: Garland

Deck Ovens. Standard gas-fired deck ovens are similar to conventional roast or bake ovens except the inside cavity has a low height, ranging from 6 to 10 inches (150-250 mm). A typical deck oven is illustrated in Figure 7-3. The bottom of each compartment is called a deck and heat is typically supplied by burners or elements located beneath the deck. The oven ceiling, floor, and walls are designed to absorb heat quickly and radiate that heat back slowly and evenly. To accomplish this, the deck is often made of ceramic material, steel, brick, or some other composition material. Deck ovens with firebrick hearths are particularly good for bottom-crust baking and are widely used for cooking both bakery items and pizza. They also can be used to cook a wide variety of other foods fairly quickly including casseroles, meats, and fish. The limiting factor is the height or thickness of the food product.

Deck ovens can be found in both freestanding and stackable configurations. Stacked ovens are typically no more than three decks high. The differences between baking and pizza deck ovens are in size and energy input rates. Decks for baking ovens are commonly 33 to 42 inches (840-1070 mm) wide and 36 to 45 inches (915-1140 mm) deep. Pizza ovens range in width from 18 to 78¼ inches (460-1990 mm), in depth from 22 to $45^{5}/_{16}$ inches (560-1150 mm) and up to 67¾ inches (1720 mm) in height.

Baking Deck Ovens—Baking deck ovens are often categorized as one-pan or two-pan ovens, depending on their ability to hold one or two standard baking sheets (18 x 26 inches (460 x 660 mm) side by side. Each oven typically has one or two oven cavities, or compartments. Some baking deck ovens have optional steam injection to assist in finishing hard-crust breads. The compartments are sized either for baking or roasting. Baking compartments are generally 7 inches (190 mm) high, whereas roasting compartments are typically 15 inches (380 mm) high.

Pizza Deck Ovens—The most common deck/pizza oven will hold six 12-inch (300 mm) diameter pizzas. Small countertop ovens will hold one to four pizzas. In many cases, pizza pans are placed directly on the oven deck. Some manufacturers recommend placing the pizza directly on the deck or hearth while others recommend using pizza screens or perforated pans. In fact, some manufacturers suggest that cook times can be reduced and product quality improved by using low, black aluminum, flat-bottomed pans rather than shiny or high-sided pans.[6] Since the oven door is often opened to check doneness or break bubbles in the crust, at least one manufacturer offers an "air door" that retains oven heat with a vertical curtain of air inside the door opening.[4] With a well-designed deck/pizza oven, a restaurant can not only satisfy its customer's appetite for pizza, but also cook a variety of foods that might otherwise be cooked in a standard oven. Typically, deck ovens utilize conduction from the hot deck as a primary means of heat transfer to the food product but there is one manufacturer that utilizes forced convection as the primary means of heat transfer.

Convection Ovens

Reflecting years of technological refinements, today's convection oven is one of the more significant developments in commercial cooking equipment. It originated as a modified conventional or standard oven developed to overcome the problem of uneven heat distribution in the cooking cavity and to provide more production capacity for a given size. Based on these attributes, the convection oven has naturally spawned a vast number of variations in terms of size, technology, capacity, and type. Almost all convection ovens are available in both gas and electric models. The concept behind the forced-air convection oven is a simple one. When food is cooking inside an oven, it is surrounded by an insulating layer of air that is cooler than the overall oven cavity temperature. A motorized fan (or blower) forces the heated air to move throughout the oven's cavity, striping away the layer of cooler air next to the food. The result is a faster, more even cooking process than that provided by standard, natural convection, radiant-heat ovens.[7] Forced convection can reduce the cook time significantly on long-to-cook items such as potatoes and can allow more food to be cooked in a period of time.

Most gas convection ovens use atmospheric rather than infrared (IR) burners although manufacturers have recently introduced several convection oven models featuring IR burners. Gas convection ovens are available with single or multiple burners. Historically, most gas convection ovens are indirectly fired. Burners are usually located at the bottom of the oven cavity, or between the cavity and the insulated oven wall. The Blodgett Oven Company introduced a direct gas-fired heating system that places the burner in the oven cavity. This 38-kBtu/h burner has an electronic hot surface ignition system.

Figure 7-4.
Full-size convection oven.
Photo: Southbend

Manufacturers differ in how they route the flue gases and how they mix them with cavity air. Gas burners may be protected from air currents by an arrangement of baffles, and the flue gases directed around or through the cavity. Alternatively, the flames and flue gases may be directed into tubes that act as heat exchangers and vent into the flue. The oven walls are usually insulated by at least 4 inches (100 mm) of rock or mineral wool, marinite or pressed vitreous fiber to retain heat within the cooking cavity.

Forced convection ovens come in “full-size” (Figure 7-4) or “half-size” capacities, depending on whether they can accept standard full-size (18 x 26 x 1 inch (460 x 660 x 25 mm)) or half-size (18 x 13 x 1 inch (460 x 330 x 25 mm)) sheet pans. Most half- and full-size ovens are capable of handling up to six sheet pans. Some of these ovens also include extra deep cavities, which allow a choice of pan direction placement. Convection countertop and range ovens are also available, as are high-capacity roll-in or rack ovens. The convection principle has also been applied to most conveyor and some rotisserie ovens.

Rack Ovens. Rack ovens are basically tall stainless steel boxes capable of high production in a relatively compact space. These large capacity, roll-in rack models fill the requirements of high-volume institutional operations. They are ideal for rethermalizing many products prepared in cook/chill systems as well as baking and roasting. The rack oven is capable of producing thousands of identical products or many diverse menu items within the same cooking cavity.

Figure 7-5.
Double-rack rack oven.
Photo: Revent

The product is placed in pans that are loaded on mobile, stainless steel or aluminum racks. The loaded racks are rolled into the oven through a large vertical entrance door. The rack is then connected to a revolving mechanism that starts smoothly and rotates slowly in a carousel motion. This method of cooking contributes to the cooking speed and product consistency.

Rack ovens are available in a variety of sizes, the most common being single and double-rack (see Figure 7-5). The racks typically hold between 10 and 15 pans, depending on spacing and type of product being baked. Rack ovens are available in models requiring 16 to 20 square feet (1.5 - 1.9 square meters) of floor space and have rated inputs ranging from 125 kBtu/h to 375 kBtu/h. Mini-rack ovens offer the uniformity and production capacity benefits of rack oven design with the smaller footprint of a standard convection oven. These ovens use a fixed, non-removable rack and are available in 6, 8 and 10-pan models, with inputs ranging from 60 to 80 kBtu/h for gas-fired units and 14 to 25 kW for electric units.

Rack ovens have heat exchangers of various designs that utilize a power blower to circulate heat evenly throughout the cavity. Self-contained steam systems are available for injecting steam into the oven cavity at the appropriate time in the baking cycle.[2]

Combination Oven/Steamers. A combination oven/steamer, or combination oven, is a convection oven that includes the added capability to inject steam into the oven cavity and typically offers at least three distinct cooking modes. In the combination mode it provides a way to roast or bake with moist heat (hot air and steam); in the convection mode it operates as a purely convection oven providing dry heat; or it can serve as a straight pressureless steamer (discussed in Section 8). In addition, some manufacturers provide holding and proofing temperature settings. Others offer high-end temperatures exceeding 550°F (290°C) to enable using the oven as a broiler. Figure 7-6 illustrates a typical combination oven.

Figure 7-6. Combination oven.
Photo: Rational

Initially, electric combination ovens dominated the market place but now most manufacturers also offer gas combination ovens. There are many different designs of combination ovens available – more than with any other specific oven type. This is mainly due to the fact that this new oven technology has not existed long enough to settle on any one standard design, and is amplified by the fact that many of these ovens are designed and manufactured in Europe. Each manufacturer has a different approach to the concept of the combination steamer. This includes multiple cavity sizes and shelf layouts as well as several different methods for generating and introducing steam to the oven cavity. Some ovens employ a traditional boiler-based steam generator design while others simply spray water on a heated metal mass within the oven or on the oven blower. Many of the combination ovens are available with complex and versatile controls systems that include programming functionality as well as a temperature sensor that feeds information to the controls system and varies the cooking cycle. These ovens might also include communications outputs that allow the operator to monitor and store food temperature information for HACCP record keeping. Some ovens utilize only a simple timer and three way switch which determines the cooking mode and duration.

Combination ovens are available in countertop sizes, which hold half-size ($10^{3}/_{8}$ x 12¾ x 2½ inch (264 x 324 x 65 mm)) steam table pans. Full-size combination ovens are capable of loads of up to 12 full-size (12 x 20 x 2½ inch (300 x 510 x 65 mm)) steam table pans. They extend to large, floor-mounted, full-sized units that accept up to 20 standard (18 x 26 inch (460 x 660 mm)) sheet pans. Even large capacity, roll-in rack models are available in the combination oven format. One unifying factor in all combination oven designs is the ease of cleanability. The fact that these ovens typically include stainless steel interiors and spray heads as well as steam generators means that they are self cleaning—a feature that gives them a distinct maintenance advantage over the sometimes hard-to-clean convection ovens.

Cook-and-Hold Ovens. Some ovens are designed specifically for cooking and holding product while others (including combination and rotisserie ovens) offer low-temperature cooking options, or cook-and-hold modes. The primary use of the cook-and-hold is to roast and hold meats at lower temperature ranges, 175° to 250°F (80° to 120°C) vs. 275° to 400°F (135° to 200°C), than are typically used for conventional cooking methods in order to help retain product juiciness as well as tenderness.[8] There are two standard types of cook-and-hold ovens. One uses natural convection with high humidity (90 - 95% humidity with minimal air movement) and slightly higher temperatures; the other uses forced convection with lower temperatures and lower humidity levels (between 30 - 60% humidity).[4] A low-temperature cook-and-hold oven is presented in Figure 7-7.

Figure 7-7.
Cook-and-hold oven.
Photo: Alto-Shaam

The basic frame, housing and interior components are often the same as those in a forced convection oven—the main difference is that a cook-and-hold oven is able to produce relatively high humidity during the cooking process. This is usually accomplished through the use of a water reservoir within the oven cavity. The forced convection cook-and-hold ovens use a blower to evenly distribute the moist heat throughout the oven cavity. Cook-and-hold ovens are available in both gas and electric models, in the same general sizes and the same rated energy inputs as basic convection ovens.

Conveyor Ovens

Conveyor ovens are available using four different heating processes: infrared, natural convection with a ceramic baking hearth, forced convection or air impingement, or a combination of infrared and forced convection. The air impingement ovens use a blower and baffles to intensify and focus the air movement within the oven cavity towards the food load. These high-velocity "fingers" of air impinge upon or blow away the layer of air and moisture that insulates the food, thus increasing the speed of the cooking process.[4] Conveyor ovens are generally used for producing a limited number of products with similar cooking requirements at high production rates. They are highly flexible and can be used to bake or roast a wide variety of products including pizza, casseroles, meats, breads, and pastries.

Figure 7-8. Double-stacked conveyor oven.
Photo: Middleby-Marshall

The ovens are available in many different sizes and configurations. They are available in sizes small enough to satisfy low-volume and niche operations, such as kiosks, that have limited production space, and large enough to meet the demands of high volume operations. Most conveyor ovens, both large and small, can be stacked up to three units high, significantly increasing production capacity without requiring increased floor space. Figure 7-8 presents a double-stacked conveyor oven.

Essentially, conveyor ovens are a rectangular housing unit containing a baking cavity or chamber, which is open on two opposing sides. A conveyor system carries the food product through the baking chamber or tunnel on a wire rack. Most ovens can be outfitted with multiple conveyor belts, each of which may have a different operating speed. The typical counter-top unit has a conveyor width as small as 10 inches (250 mm) and a cavity length of 14 inches (350 mm). Freestanding units may have conveyor widths that range from 14 to 37 inches (350 mm-950 mm) and cavity lengths ranging from 20 to 75 inches (500-1900 mm). Oven controls adjust both the cavity temperature and speed of the conveyor. In some models, the top and bottom heat input are independently adjustable. Many of the larger conveyor ovens have a hinged glass door along the front side of the tunnel to allow loading and unloading of food that requires a shorter cook time.

One of the newer features included on some conveyor ovens is the option to have independently controlled cooking zones. The temperature within each zone may be independently adjusted. The first zone is very hot and as the product passes through it, it is quickly heated up to cooking temperature. Before it starts to burn, the product is moved into the second zone, which is maintained at a considerably lower temperature. In this zone the product cooks at an even rate until it reaches the third zone, generally referred to as "the finishing" zone. Here the temperature is even lower, cooking the product to the desired degree of "doneness". One manufacturer has expanded upon the multiple-zone concept by allowing each eight-inch length of tunnel to have a different operating temperature.[4]

A few manufacturers offer an air-curtain feature at either end of the cooking chamber that helps to keep the heated air inside the conveyor oven. The air curtain operates as a virtual oven wall and helps reduce both the idle energy of the oven and the resultant heat gain to the kitchen.[4]

Rotisseries

A rotisserie is fitted with one or more mechanically rotated spits that hold meat or poultry in position near a fixed heat source while the food is slowly being cooked on all sides. The heat source may be gas or electric and several models also offer an additional wood-fired option. Rotisseries can be separated into two main categories: rotisserie ovens and rotisserie broilers. Within these, many models are available.

Rotisserie Ovens. Rotisserie ovens are designed for batch cooking, with individual spits arranged on a rotating wheel or drum within an enclosed cooking cavity. Figure 7-9 presents a typical electric rotisserie oven. The ovens can be equipped with either single action rotation cooking or a dual rotating action, planetary cooking system that incorporates convection, radiant, and air impingement cooking. Motors provide the labor saving power to rotate both types of cooking systems.

Figure 7-9.
Rotisserie oven.
Photo: Hobart

For gas rotisserie ovens a number of burner systems are available. Single heat-source systems include atmospheric flame type, radiant and infrared. There are also dual burner systems that combine infrared with an open flame. Most gas models feature electronic ignition systems.

Rotisserie ovens range in size from high-volume floor models to space-saving countertop models. Most models are equipped with basic time and temperature controls, optional cook-and-hold controls, or more sophisticated control packages with programmable channels. Electric models may feature interior halogen merchandising lights.

Rotisserie Broilers. The rotisserie broiler is designed for continuous loading and cooking, with vertically stacked spits. Some models feature individual drive systems, which utilize a chain link from gear to gear to maintain the tension, allowing operation of one or more spits at any time. The rotisserie broiler employs super heated fire bricks strategically located over powerful pipe burners (e.g., 40 kBtu/h each with a total input rate between 105 kBtu/h to120 kBtu/h for a median of 112 kBtu/h, or roughly twice that of the rotisserie oven at 50 kBtu/h), which in turn, emit radiant heat. Unlike rotisserie ovens, rotisserie broilers have very rudimentary controls.

Controls

Standard Oven Controls

Standard ovens usually have simple controls, limited to a thermostat and a selector that allows the oven to bake or broil. Sensors may be electronic, but the more common ones are usually the mechanical bulb type (modulating thermostats), which adjust the burner incrementally and have a tendency to be somewhat uneven in temperature distribution. On/off snap action thermostats provide better temperature control, but add to the initial cost. Gas deck/pizza ovens use shut-off and adjustment valves for the gas control and usually feature automatic safety pilots and ignition. Vents get rid of the flue gases and generated steam, providing crisp crusts on the pizzas.

Convection Oven Controls

In general, convection ovens, including conveyor ovens as well as convection rotisseries, offer more control over the cooking process than standard ovens. Upgraded controls include more accurate electronic sensors and thermostats, electronic ignition controls (on gas models), and on many of the newer gas and electric models, programmable cooking computers which recall several cooking sequences by the simple press of a button. Some of these ovens can be programmed to first cook and then hold food products. Food may be cooked at a high temperature with high convection and then held for an extended period at a lower temperature with the fan off.

Some ovens allow the user to control cooking by regulating fan speed, temperature, humidity and the cooking time. (The speed of the fan affects cook time and uniformity, as does the pattern of airflow through the interior.) In combination ovens, for example, a cook cycle may be programmed to begin with high steam and convection, then continue cooking with convection only, and hold the finished product at low temperature and moderate humidity. Other options included in many of these ovens are a low-speed fan setting to permit cooking of delicate items and a rapid cool down mode to facilitate going from oven to steaming quickly.

Microwave and many other rapid cook ovens control neither the temperature nor the humidity and instead base the cook cycle on a precisely timed program or algorithm that has been predetermined for the type of food being cooked.

Heating Technologies

Indirect-fired ovens have the gas burners and heat exchangers located outside the cooking cavity. The hot products of combustion heat the bottom, sides and top of the oven without entering the cooking cavity. Direct gas-fired ovens typically position the burners below the cooking cavity and allow the hot combustion products to route through the cooking cavity rather than around it. Heat is transferred directly from the hot gases to the food. If an oven section has two compartments, they may or may not be independently heated and controlled. Usually the cavity walls are insulated with 2 to 4-inch (50-

100 mm) heat-stable fiberglass, vitreous fiber or rock wool on the sides and top with 2 inches (150 mm) of insulation in the door.

Advanced Oven Technologies

Recently, ovens have begun to evolve technically at an increased rate as new technologies have been introduced to the market. Manufacturers improved the standard or natural convection oven into the modern-day forced convection oven simply by adding a fan but improvements in burner design and new heat transfer options are driving the modernization of the oven far beyond this simple improvement. More efficient infrared burners are replacing the traditional atmospheric burners in gas ovens; quartz halogen lamps cook food using a combination of infrared energy and visible light; circulating thermal fluids make conduction cooking and holding possible; and a combination of microwave and convection are playing a part in electric oven designs. Combining technologies such as infrared with forced convection or convection with steam injection, recirculating combustion gases via specially designed fans or venting tubes all add up to improved oven performance. Additionally, some oven manufacturers are coupling custom fitted ventilation hoods with their oven designs.

Infrared Burners. An infrared/forced convection oven combines the penetrating heat of infrared radiation with the convective effect to reduce baking time as compared to natural convection ovens.

Air Impingement. Air impingement is a relatively new technology applied to conveyor and some rotisserie ovens. Air impingement typically uses a ported manifold to direct jets of air, or “fingers,” onto the product’s surfaces.

Quartz Halogen Lamps. Quadlux, Inc., the Northern California manufacturer of the Flashbake® oven pioneered the use of quartz halogen lamps to cook food using a combination of infrared energy and visible light. The infrared energy cooks from the outside in, browning and crisping the exterior, as would a conventional oven. The visible light penetrates into the food a short distance, with the depth varying depending on the color and composition of the food. The quartz lamps used in the oven design were first used to cure silicon chips for the microprocessor industry. The lamps start up instantly,

Figure 7-10.
Flashbake® oven.
Photo: Vulcan-Hart

thus have no preheat time, and remain off when idle. This oven however, typically uses as much or more energy than conventional ovens when cooking.[9] This technology allows a substantial amount of energy to impinge on the food product and greatly reduces the cook time. Because of the speed of cooking and the use of a non-standard heat transfer technology, this hybrid oven falls into the category of "rapid cook" ovens. This technology has subsequently been licensed to other manufacturers (Figure 7-10) and has recently been applied to conveyor ovens.

Conduction. Heat is transferred to the foods via direct contact with a heated medium. For example, many pizza ovens incorporate a firebrick or composite hearth with burners or elements underneath the hearth. The bottom of the pizza is cooked by direct contact with the hot hearthstone. This process of conduction, combined with the circulation of hot air above the pizza, allows good control of the cooking speed and texture of both the crust and toppings. Another recent entry into the market place is an electric cook-and-hold conduction oven that circulates heat transfer fluids through the oven's hollow shelves. The heat is conducted directly through the shelves to the pans and subsequently to the food. This method of heat transfer, according to the manufacturer, allows food to be brought evenly to a cooked state without burning or drying.

Combination Convection Microwave. Two ovens on the market[10] combine convection with microwave for high-speed cooking. Like the quartz halogen ovens, this hybrid heat transfer combination falls into the rapid cook category. The TurboChef®, pictured in Figure 7-11, uses a modified high-velocity impingement system that propels hot air directly down onto the food, then pulls it around and underneath the product. This process is coupled with a microwave component to dramatically speed the cooking process. Amana's Convection Express takes a similar approach to the TurboChef® and includes a single cooking chamber and a compact, stackable design. It includes 1000 watts of microwave energy and 2,700 watts of convection heating. With this cooking combination comes a host of usage options including the ability to program a multi-stage cooking sequence. For example, a frozen dish can be defrosted through the microwave-only function, then put through a fast-heating stage on a convection cycle, then baked by both mi-

Figure 7-11.
TurboChef® oven.
Photo: TurboChef®

crowave and convection heat and, finally, browned with a dose of convection-only heat with single programmed recipe. While these ovens have typically been electric only, a new gas convection microwave oven is in development and should be commercially available in the near future.

Combination Halogen Microwave. The latest hybrid or rapid cook oven on the market combines the quartz halogen cooking with microwave. As with the convection microwave, this oven offers a variety of cooking options and multi-stage cooking programs, all designed to produce consistent product while dramatically reducing product cook time.

Oven Performance

The work of an oven can be outlined as bringing the cavity from room temperature up to cooking temperature (preheating), holding the cavity at cooking temperature until cooking begins (idling), and restoring heat to the cavity when cold food is placed into the oven (recovery).

The Food Service Technology Center has developed several Standard Test Methods for assessing the performance of ovens, which have been ratified by the American Society for Testing and Materials (ASTM).[11-16]

These test methods allow manufacturers and end users to accurately compare the performance and energy efficiencies of different models and configurations of ovens, and to evaluate oven-energy performance as well. As hard data on ovens becomes available, it is apparent that certain technologies and designs yield better performance.

Oven performance is characterized by energy input rate, preheat time and energy consumption, idle energy consumption rate, pilot energy consumption rate, cooking-energy efficiency, production capacity, and cooking uniformity.

Energy Input Rate

Energy input rate is one of the basic criteria for oven selection. It is the maximum rate at which an appliance draws energy, expressed in kBtu/h or kW. A well-designed, energy-efficient oven can operate with a lower input rate and still produce as much or more food product as an oven with a lower quality design and a higher rated input. Initial cost of the energy-efficient oven may be higher, but the long-term operating costs will be lower.

Preheat Energy and Time

Preheat Time. Preheat time is the time required to raise the cavity from room temperature to cooking temperature (typically 350°F (175°C)). Ovens are usually left on during the day, so preheat time may not be important to the operator. Preheat time is determined by energy input rate, cavity size, heating technology and control strategy. Knowing the preheat time allows an operator to effectively schedule oven start-up and shutdown times, so that the oven does not need to be operated continuously from opening until closing.

Preheat Energy. The energy required to preheat a oven is a function of the cavity size of the oven and its heat-up efficiency. However, preheat energy consumption represents less than 15% of the daily energy consumption for a oven that was turned on once over an 8-hour operating period.[4] For longer operations (e.g., 16 hours), the energy performance of the oven during this phase of its operation becomes less important.

Idle Energy Rate

The idle energy rate is the amount of energy consumed per hour when the oven is turned on and holding at operating temperature without a food load. The idle-energy consumption rate is a function of the thermostat set point and the effective resistance of the oven cavity to heat loss. Some ovens, especially conveyor ovens, exhibit significant idle energy rates.

Monitoring the usage of ovens in commercial kitchens[4] has demonstrated that they spend a significant proportion of their “on time” in idle mode and that the rate of idle energy consumption has a significant impact on total daily energy consumption.

Cooking Energy Rate and Efficiency

Cooking energy rate is the rate at which an oven consumes energy while it cooks a load of food. It is reported in kBtu/h or kW. Cooking-energy efficiency is the ratio of energy added to the food and total energy supplied to the appliance during cooking:

$$CookingEfficiency = \frac{E_{Food}}{E_{Appliance}} \times 100\%$$

The ASTM standard test methods define cooking rates and efficiencies for heavy-load (full-cavity), medium-load (half-capacity) and light-load (single-pan) conditions. Due to variances in burner and heat-exchanger design, gas ovens demonstrate a dramatic difference in heavy-load cooking energy efficiencies.

Production Capacity

Production capacity is the amount of food that can be prepared in an oven in a given time period and is directly related to the cook time. A shorter cook time for a given food product results in a higher production capacity. It is one of the most important factors in selecting the right oven for a kitchen because it allows an operator to match an oven to the anticipated production requirements of a facility. An oversized oven, with an unnecessarily high production capacity, could cost the operator in up-front capital while an undersized oven could create a bottleneck that would impede the product output of the entire kitchen. Production capacity is typically reported in pounds per hour (lb/h) of food cooked although in some cases (deck ovens, conveyor ovens, and rapid cook ovens) the production capacity is also reported in pizzas cooked per hour. For convection ovens, the ASTM test method determines production capacity by cooking loads of potatoes and the result is reported in pounds of potatoes per hour. FSTC testing showed production rates of approximately 70 lb (32 Kg) per hour for both the gas and electric full-size convection ovens and around 40 lb (18 Kg) per hour for the half-size ovens tested.[17]

Cooking Uniformity

Cooking uniformity is a measure of the ability of an oven to cook food evenly no matter where it is placed in the oven or how the oven is loaded. For example, the ASTM test method for convection ovens measures uniformity by baking a fully loaded oven of white sheet cakes and comparing the browning patterns. It is very difficult for an oven to display perfect uniformity without engineering the airflow within the oven cavity. Many of the cake-browning tests performed at the FSTC have reflected some level of uneven cooking, from front-to-back and from rack-to-rack.[17] The testing effectively highlights the design differences between ovens. A poorly designed oven may burn food on the top rack before it finishes cooking the food on the center rack. Convection ovens with uneven airflow may burn the side of the food closest to the fan while the other side is barely browned.

Advanced burners are being developed by the gas industry to improve the uniformity in the burner section through the use of ported infrared burners and inconel wire mesh burners. These developments have the potential to improve cooking uniformity as well.[18]

Benchmark Energy Efficiency

The ASTM Standard Test Methods allow manufacturers and users to compare the cooking-energy efficiency of different ovens within comparable oven categories. For example, in the test method for convection ovens, energy efficiency is determined by fully loading an oven with potatoes and then cooking them to a predetermined temperature of 205°F (96°C). Typical energy efficiencies for convection ovens under these cooking scenarios, along with the other oven types are summarized in Table 7-1.

Gas ovens, by the very nature of their heat transfer from the combustion of gas are less efficient than their electric counterpart. In standard gas ovens, the combustion chamber and flue passages are located between the oven cavity and the exterior cabinet. The hot products of combustion indirectly heat the oven cavity by conduction through its walls. The hot flue passages also may be close to the exterior, causing heat losses to the environment. Modern convection ovens circulate flue gases through passages built into the oven cavity walls resulting in better thermal coupling and significantly improved efficiency.[4] Two types of recirculation systems are currently available; one uses a specially designed fan, the other uses a recycling or “snorkel” tube. Both systems reuse the hot air, which would normally be vented.

Table 7-1. Oven Energy Efficiency. [a]

	High-Efficiency Gas (%)	Standard Gas (%)	Electric (%)
Std/Conv/Comb	40 - 50	30 - 40	50 - 80
Deck		20 - 30	40 - 60
Conveyor	40 - 50	10 - 20	20 - 40
Rotisserie		20 - 30	50 - 60

[a] Energy efficiency numbers are based on FSTC test data from applying the ASTM Standard Test Methods to convection ovens, and on preliminary estimates for combination ovens, deck and conveyor pizza ovens, and rotisseries.

As pointed out by A.D. Little in their characterization of commercial ovens, efficiency improvements of gas-fired ovens has consisted mainly of controlling burner excess air through the use of power burners.[18] Convection oven technology can also be viewed as an energy conserving measure since the cooking time associated with convection cooking is shorter, thus reducing the overall energy consumption required during the cooking process. Direct-fired ovens, consequent to the gas flame being in direct contact with the oven cavity and food products being cooked, require less energy to do the same amount of work as indirect-fired ovens. A.D. Little projects energy efficiencies associated with these ovens to be in the 45% range. They also speculate that the successful application of air impingement to conveyor ovens will drive the efficiency of these gas models into the 40% range versus the current 10% - 20% limits.

Oven Energy Consumption

Projected energy consumption for gas and electric ovens are presented in Table 7-2 and 7-3. Based on Pacific Gas and Electric Company’s in-kitchen monitoring at its production-test kitchen, average energy consumption rates for convection ovens reflect duty cycles of 35% for a full-size gas convection oven, 40% for a half-size gas oven and 25% for both electric full-size and half-size ovens.[19-23] It was assumed that the usage patterns for countertop models would be similar to half-size convection ovens.

Duty cycles for deck ovens were assumed at 30% for gas ovens and 20% for electric ovens based on data from a proprietary unpublished end-use study. Similarly, a duty cycle of 50% was assumed for both gas and electric conveyor ovens. Rotisserie duty cycles were based on data generated by the Food Service Technology Center.[24] The duty cycle of an appliance is defined as the average rate of energy consumption expressed as a percentage of the rated energy input or the peak rate at which an appliance can use energy.

A study[8] at the Food Service Technology Center showed that a fully loaded combination oven used to cook whole chickens could cost 30% more per load in the combination mode than in the convection mode with only a minimal reduction in cook times and little discernible difference in product quality or yield. This increase in energy consumption was driven by the energy needed to create a constant supply of steam in combination mode and is illustrative of the need to use the combination mode sparingly and appropriately. Moderate use of the combination mode at the beginning of the cook cycle can reduce the product cook time without significantly impacting energy consumption; however, indiscriminate use of the combination mode throughout the entire cook cycle, as per the example above, can lead to dramatically increased operational costs for these appliances. Likewise, the cost to preheat an oven in the combination mode is about double that of convection mode because the boiler must be preheated as well.

Daily energy consumption for ovens was calculated by multiplying the median rated energy input for each oven category by the respective duty cycle and the hours of operation. Typical operating hours were gleaned from in-kitchen energy-use monitoring experiences and observations as well as on the PREP study[25] and proprietary end-use monitoring reports. Projected annual energy consumption was determined by assuming a 6-day per week, 52-week per year operation.

Table 7-2. Projected Energy Consumption for Gas Ovens.

	Nominal Size (w x d)	Rated Energy Input (kBtu/h)	Duty Cycle (%)	Avg. Energy Consumption (kBtu/h)	Typical Operating Hours (h/d)[a]	Annual Energy Consumption (kBtu)[b]
STANDARD/CONVECTION/COMBINATION						
Full-Size	38" x 38"	40 - 100				
(Median)		70	35[d]	25	8	62,400
Half-Size	30" x 26"	20 - 40				
(Median)		30	40[e]	12	6	22,500
Countertop	20" x 22"	15 - 20				
(Median)		18	40[f]	7	4	8,740
DECK [g]		20 - 120				
(Median)		70	30[h]	21	10	65,500
CONVEYOR		120-150				
(Median)		135	50[i]	68	10	212,000
ROTISSERIE		40 - 60				
(Median)		50	60[J]	30	8	74,900

[a] Operating hours or appliance "on time" is the total period of time that an appliance is operated from the time it is turned "on" to the time it is turned "off".

[b] The annual energy consumption calculation is based on the average energy consumption rate x the typical operating hours x 6 days per week x 52 weeks per year.

[c] Includes cook & hold ovens.

[d] The duty cycle is based on monitoring a full-size gas convection oven with an input rate of 72 kBtu/h in a real-world production kitchen.[19] An associated average energy consumption rate of 25 kBtu/h was calculated.

[e] The duty cycle is based on monitoring a half-size gas convection oven with a rated input of 35 kBtu/h in a real-world production kitchen.[20] An associated average energy consumption rate of 12 kBtu/h was calculated.

[f] A 40% duty cycle has been assumed for countertop ovens based on the assumption that the usage pattern is similar to half-size oven operations.

[g] Includes bake, roast, combination and pizza ovens.

[h] A 30% duty cycle has been assumed for deck ovens based on data from an unpublished proprietary end-use monitoring study.

[i] A 50% duty cycle has been assumed for conveyor ovens based on data from an unpublished proprietary end-use monitoring study.

[j] A 60% duty cycle has been assumed based on Food Service Technology Center laboratory rotisserie testing.[24]

Table 7-3. Projected Energy Consumption for Electric Ovens.

	Nominal Size (w x d)	Rated Energy Input (kW)	Duty Cycle (%)	Average Energy Consumption (kW)	Typical Operating Hours (h/d)[a]	Annual Energy Consumption (kWh)[b]	(kBtu)[c]
STANDARD/CONVECTION/COMBINATION[d]							
Full Size	38" x 38"	10 - 40					
(Median)		25	25[3]	5	8	12,500	42,600
Half Size	30" x 26"	6 - 10					
(Median)		8	25[f]	2	6	3,740	12,800
Countertop	20" x 22"	2 - 6					
(Median)		4	25[g]	1	4	1,250	4,260
DECK[h]		6 - 12					
(Median)		9	20[i]	2	10	6,240	21,300
CONVEYOR		35 - 45					
(Median)		40	50[j]	20	10	62,400	213,000
ROTISSERIE		4 - 12					
(Median)		8	65[k]	5	8	12,500	42,600

[a] Operating hours or appliance "on time" is the total period of time that an appliance is operated from the time it is turned "on" to the time it is turned "off".

[b] The annual energy consumption calculation is based on the average energy consumption rate x the typical operating hours x 6 days per week x 52 weeks per year.

[c] Conversion Factor: 1 kW = 3.413 kBtu/h.

[d] Includes cook & hold ovens.

[e] The duty cycle is based on monitoring a full-size electric convection oven with an input rate of 16 kW in a real-world production kitchen.[21] An associated average energy consumption rate of 5 kW was calculated.

[f] The duty cycle is based on monitoring two half-size electric convection ovens with a rated inputs of 5 kW each in a real- world production kitchen.[22,23] An associated average energy consumption rate of 2 kW was calculated.

[g] A 25% duty cycle has been assumed for countertop ovens based on the assumption that the usage pattern is similar to half-size oven operations.

[h] Includes bake, roast, combination and pizza ovens.

[i] A 20% duty cycle has been assumed for deck ovens based on data from an unpublished proprietary end-use monitoring study.

[j] A 50% duty cycle has been assumed for conveyor ovens based on data from an unpublished proprietary end-use monitoring study.

[k] A 60% duty cycle has been assumed based on Food Service Technology Center laboratory rotisserie testing.[24]

Ventilation Requirements

Some recent building codes and guidelines reflect the differences between gas and electric oven characteristics, while others do not. The *1995 ASHRAE Applications Handbook* classifies both gas and electric ovens as light duty with respect to ventilation requirements. Typical ventilation rates for a listed (e.g., ULC), wall-mounted, canopy hood range from 150 to 200 cfm (75 to 100 L/s) per linear foot.[26]

Ovens may be equipped with a standard draft hood, which may be directly vented to a flue or chimney. This may eliminate the need for an exhaust hood for these ovens when used to prepare food product that does not produce grease.

Integrated Ventilation Systems. Several oven manufacturers have integrated appliance-specific ventilation hoods in their oven designs. Designing hoods for a given model eliminates the risk of mismatched or incompatible equipment. The In-Vent™ integrated ventilation hood for Blodgett's Master-Therm conveyor oven is a revolutionary new vent system designed to minimize heat gain—both radiant and convective as well as the net exhaust requirement. Its unique configuration surrounds the majority of the oven's exterior and makes optimum use of untempered make-up air. This, in turn, reduces the load on the restaurant's HVAC system while providing increased operator comfort. Also, because of its enclosed nature, this system is quieter than canopy hood ventilation systems. Another company–Franklin/Southern Pride–has integrated a hood with their rotisserie system. Although the system is currently restricted to the rotisserie oven, Franklin plans to accommodate their other ovens in the near future.

Research and Development

Insulation. One of the key features of any piece of food service equipment is its energy efficiency. For cooking appliances such as ovens in particular, this number is an invaluable indicator of how much energy will be applied toward cooking the food and how much will be wasted or lost. Cooking-energy efficiency is controlled by two primary factors: how heat is imparted to the food and how heat loss is controlled. The first factor involves such concepts as effective air circulation within the cooking cavity and will be discussed later.

Today, most oven manufacturers have realized that insulation is essential to minimizing heat loss in the cooking process— appliances with effectively incorporated insulation perform better than those without. This can be easily determined by comparison of their cooking energy efficiencies. The proper amount or thickness and the proper R-value of insulation are critical in minimizing the amount of conductive heat transfer through oven cavity surfaces. Studying insulation use in ovens is an effective way of promoting energy efficiency and energy-conscious designing in the industry.

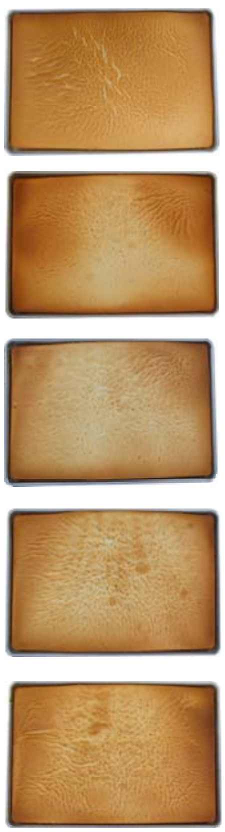

Figure 7-12.
Sheet cake uniformity.

Air Circulation and Cooking Uniformity. Air circulation within an oven cavity is another basic concept behind convection ovens as well as other devices. It is the underlying principal of convective heat transfer cooking; without proper air circulation there would be little or no heat transfer. For appliances such as convection ovens, adequate hot air distribution promotes uniform cooking and high energy efficiencies. In order to achieve proper air circulation, several basic features need to be considered: fan speed and sizing, cooking cavity design and geometry, and location of flue gas inlet and exit (for direct-fired ovens). Existing standard test methods incorporate techniques to determine the effectiveness of air circulation components in ovens and challenge their cooking uniformity ability. For example, one test monitors an array of food temperatures that are distributed throughout the cooking compartment. Another example is the sheet cake browning uniformity test, which shows darker and lighter surface areas that produce qualitative results indicating how well heat is circulated and transferred to various sections of an oven (see Figure 7-12). Together these techniques are used to establish an oven's cooking uniformity profile.

As long as tests are conducted to measure cooking and heating inconsistency within ovens, designs will improve and energy efficiencies will follow accordingly. Manufacturers are constantly refining oven design and geometries to optimize performance and heat transfer, yielding better cooking uniformity in the long run. As these oven technologies advance, testing of these appliances will ultimately be the deciding factor and basis for more and more of today's consumer decisions.

Moisture and Humidity. One of these advanced technologies that is used in many ovens today is moisture and humidity control. In proofing ovens, breads and similar items are held in an environment where the interior humidity is controlled; it is in this "proofing" stage that the moisture is utilized to increase the bread volume after the loaves have assumed their form. Similarly, combination ovens inject steam into the cooking cavity to induce various food qualities such as the crustiness and golden brown color in breads. In direct-fired ovens, hot combustion gases which contain water vapor are routed directly into the cooking cavity. Humidity control and moisture interaction with foods are areas that deserve further research and testing of this cooking process will greatly improve consumer understanding and equipment selection.

Food Quality and Appearance. While much focus and emphasis in the research and testing of food service equipment is placed on energy use, efficiency and productivity, there is also a concern among manufacturers and end users about the quality and appearance of the foods that are cooked. Due to the varying technologies employed by the vast array of ovens in the food service industry, there are differences in the quality of their finished products. More specifically, within the classification of direct and indirect-fired ovens, aside from the concept and design differences, other disparities can also exist with regards to the final food quality, depending on exactly what is being prepared.

Figure 7-13.
Pinking of meat.[27]

Photo: Courtesy Cornforth, Utah State University.

One particular issue that warrants the need for further investigation is the undesired pinking of meats (see Figure 7-13), especially chicken, pork, and turkey, when cooked in direct-fired gas ovens. In the public eye, a pink coloration in cooked meat products is normally considered an indication of the food being underdone, even if the meat has been properly cooked. The phenomenon of pinking in cooked meats can be attributed to the reaction of combustion gases or byproducts, which are forced into the cavity in direct-fired ovens, with the internal chemicals found in all meats. These cases have been studied and observed to occur even after various meats were cooked to temperatures in the range of 180°F. Researchers have found direct correlations between the presence of combustion byproducts such as carbon monoxide and the occurrence of pinkness in the final food product.[27] Their research associates this coloration with the interaction between oven flue gases and the water contained in the meats, which together yield higher acidity levels that promote the ideal conditions for pinking. These resultant acidic chemicals disassociate into nitrites (chemical formula NO_{3-}),[27] which coincidentally, are used in the preparation of cured meat products to produce a desired pink color.[28] In one scenario, these nitrites are what meat preparation companies use to purposefully cure meats to a desired pink tone; however in another it is the same chemical that ultimately causes an undesired effect when meats are cooked in direct-fired ovens (see Figures 7-14 and 7-15). Thus far, this is an issue that greatly affects public opinion and end user satisfaction.

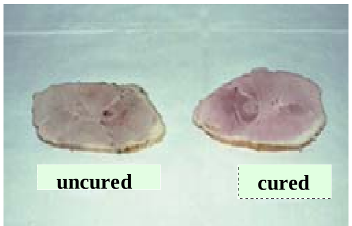

Figure 7-14.
Uncured meat (left); cured meat (right).[27]

Photo: Courtesy Cornforth, Utah State University.

While direct-fired ovens have an advantage over indirect-fired gas convection ovens in the areas of energy efficiency and cook time, the indirect-fired oven (by its very definition) and intrinsic nature (no combustion gases in the oven cavity) does not produce meats that experience the pinking effect. Although direct-fired ovens have created a niche for themselves as an effective kitchen appliance, this harmless pink coloration may cause adverse effects such as end users choosing to focus on or switch over to indirect-fired ovens. Perhaps the occurrence of the pink coloration needs to be addressed in the classification and performance testing of direct and indirect-fired gas convection ovens. Tests would reflect the flue gas distribution design and indicate the tendency of meats cooked in tested ovens to experience this pinking effect. Therefore, it stands to reason that further industry wide research needs to be conducted to solve or eliminate the pinking of meats in direct-fired ovens. More importantly, research and studies of this phenomenon need to be brought to the attention of manufacturers and end users in order for them to be educated about why this happens and what can be done to avoid it. Industry awareness of this problem has already prompted one manufacturer to acknowledge this phenomenon and emphasize the fact that they are able to avoid this issue, while maintaining performance with the use of indirect gas streams within heat exchangers in their indirect-fired gas convection ovens.

Figure 7-15.
Pink ring around meat cooked in direct-fired oven.[29]

Photo: Courtesy Cornforth, Utah State University.

Industry Market Focus

As with other classes of cooking equipment, the average efficiency of ovens is more dependent on tendencies of end users to purchase more efficient equipment than on any future technology developments.[18] There is a need for the food service industry to better benchmark the energy performance for all types of ovens. An opportunity exists for the utilities to promote higher efficiency and production capacity ovens with the best cooking uniformity—but the database needs to be expanded.

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